Laboratory strength assessment of athletes

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by Warren Young

Field tests for the assessment of progress in the development of strength qualities have the advantage of being event specific. However, their drawback lies in their inability to determine which specific quality has influenced any improvement shown, be it technique, maximum strength, speed strength or reactive strength. The author describes an assessment system developed at the Australian Institute of Sport, which is not only specific to the nature of the event but is also able to differentiate between the various strength qualities. The system is called the 'Strength Qualities Assessment Test' (S.Q.A.T.). It is designed to assess the strength qualities of the leg extensor muscles, assuming that these have the greatest influence on the movements of running and jumping.

It is suggested that this test, used in conjunction with traditional field tests, will give a more accurate picture of the athlete's progress.

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1 Introduction

Assessment of strength qualities should be conducted for two main reasons. Firstly, an athlete profile can be generated, which assists the coach in identifying specific strengths and weaknesses. This is important for individualizing the training programmes. Secondly, the training process can be monitored, to check that programmes are achieving their intended objectives.

Once a commitment is made to conduct a strength assessment, a decision has to be made regarding the selection of tests. Many coaches are familiar with the large variety of field tests available, e.g. standing long and triple jumps, vertical jump, overhead shot throw etc. An advantage of these and other field tests is that they can be quite event-specific. On the other hand, this can cause difficulties with the interpretation of test results.

Let us consider the standing triple jump as an example. Performance in this test is influenced by several factors, including maximum strength, general speed-strength qualities, reactive strength and, of course, technique. Therefore, if an athlete improves his test result, we can not be sure which specific strength quality has improved or if it is due totally to imported technique. It is well accepted that training should be periodized, to emphasize the development of specific components at different times. For example, a jumper may emphasize maximum strength, using heavy weights, at one time and switch the emphasis to the development of reactive strength, utilizing plyometrics, at another time. Therefore in order to monitor the expected training effects, it is necessary to attempt to isolate these strength qualities or components of performance.

An inherent problem with field tests is that they tend to measure a mixture of qualities and therefore are incapable of isolating the various components of performance. In oder to overcome this problem, tests can be devised in the laboratory that can reduce the influence of skill and isolate qualities but still contain any sport-specific features.

A laboratory assessment system, designed to assess the strength qualities of the leg extensor muscles, has been developed at the Australian Institute of Sport (AIS). The protocol is intended to be specific to running and jumping movements and is especially valuable for track and field. Previously, laboratory tests have suffered from not being specific enough to the demands of the various sports. Two problems can occur in this situation. Firstly, the tests may be capable of separating elite from average athletes but may not be sophisticated enough to be able to distinguish between individual athletes within a homogenous group e.g. elite male jumpers. Secondly, the test may be insensitive to training gains. For example, athletes may improve their jumping ability following plyometric training but the test reveals no improvement, because it is not specific enough to the nature of the training, e.g. an isokinetic knee extension test (Olson et al, 1993).

The system used at the IAS, which involves tests conducted from an upright squat position, has been named the 'Strength Qualities Assessment Test' (S.Q.A.T.). The SQAT battery is specific to running and jumping movements, including those used in track and field events, in a number of ways.

(a) Muscle groups involved

The production of propulsive force in sprinting and jumping comes primarily from hip, knee and ankle extension. Therefore the gluteal, quadriceps, hamstring and calf muscle groups are those targeted by the SQAT battery.

(b) Movement pattern

Sprinting and jumping involve a multi-joint movement, which therefore requires the leg extensors to contract in a co-ordinated fashion. SQAT uses jump movements that activate the leg extensors in a pattern more similar to sprinting/jumping than tests that isolate individual muscles, e.g. single leg knee extension. Also, the upright position required during leg extension involves the stabilizing trunk and pelvic muscles, also considered important for sprinting and jumping.

The range of motion at the knee is fairly small during the take-off phase of the long jump (KARAYANNIS, 1978), the high jump (CONRAD and RITZDORF, 1990) and the support phase of sprinting (BLOUNT et al, 1990). Therefore, SQAT includes tests using a similar range; e.g. from a squat position producing a 120° knee angle.

(c) Contraction type

Sprinting and jumping movements involve acceleration of the body mass. SQAT includes jumping against a constant mass, so that the resulting acceleration would be expected to produce a more similar muscle activation pattern than test modes that modify the resistance throughout the range of motion e.g. isokinetic machines that utilize 'accommodating resistance'.

Running and jumping support phases consist of eccentric-concentric contractions (stretch-shortening cycle [SSC]) of the leg extensors. The ability to utilize stretching of the muscle and then change quickly from an eccentric to a concentric contraction can be defined as reactive strength. SSC movements have been classified as fast (100-250ms duration) and slow (>250ms) (SCHMIDTBLEICHER, 1992). Although sprinting and jumping contacts are examples of fast SSC actions, the SQAT battery can generate reactive strength scores under both conditions.

(d) Speed of contraction/movement

The support phase of sprinting may be as short as 80ms for top athletes (TIDOW, 1990) and only a portion of this time can be used for propulsion during leg extension (Concentric contraction). Therefore it is desirable to assess very fast force production capabilities. The SQAT identifies the force generated at 30ms from the start of a dynamic concentric contraction, as well as the force and impulse achieved in a pre-determined time, eg. 100ms from the onset of contraction.

2 Description of the protocol

Test measures describing maximum strength and speed-strength fall into two categories; jump height and force-time measures.

2.1 Jump height

Jump height is determined by two methods. The first method records the height achieved as the athlete jumps with a light bar (9kg) resting on the shoulders. Bar displacement is obtained from the 'Plyometric Power system' (PPS) [Plyopower Technologies, Lismore, Australia]. This consists of an adapted Smith machine, which allows the bar to slide vertically on low friction sliders. A rotary encoder is used to measure bar movement from a standing position to the highest point of the jump. The initial bar position can be adjusted by 1cm intervals to produce a desired knee angle in a squat position.

Figure 1: Jump height measuring device

The second method which requires the athlete to jump with the hands kept on the hips, is based on the flight time of the jump. This method has been found to be a valid measurement of jump height (KOMI and BOSCO, 1978). A contact mat is used to record both flight and contact times.

2.2 Force-time measurement

A 19kg bar is used within the PPS and is positioned so that it produces a 120° knee angle in a squat position. The athlete is instructed to jump vertically by extending the legs as rapidly as possible. The emphasis is placed on fast force production, not the height of the jump. No dip or countermovement is possible, so that the resulting contraction is purely concentric. A force platform mounted under the feet records the take-off forces and the resulting force-time curve is analyzed by computer to display immediately the results of various speed-strength qualities.

3 Test measures

3.1 Speed-strength

3.1.1 Jump height

- *Squat jump (SJ)*

  This is a maximum jump for height with a 9kg bar resting on the shoulders from a static squat position with a 90° knee angle. This is a basic measure of leg explosiveness under concentric contraction conditions.

- *Countermovement jump (CMJ)*

  This is performed under the same conditions as the SJ but a countermovement (eccentric contraction) is produced immediately prior to the extension of the legs, which results in a higher jump than the SJ.

- *Reactive strength (slow SSC/low stretch loads)*

  This is calculated as CMJ-SJ and is considered to be a measure of the ability to utilize the muscle pre-stretching during the CMJ. The knee bend during the CMJ is fairly large (minimum knee angle about 90° and therefore the entire SSC movement is fairly slow (>500ms). Also, since the eccentric or stretch load placed on the leg extensors during the countermovement is fairly low, this quality is considered to be a measure of reactive strength under slow SSC and low stretch load conditions.

- *Reactive strength (fast SSC/high stretch loads)*

  This is measured from a depth or drop jump (DJ), utilizing a variety of drop heights (30, 45, 60cm), to impose various stretch loads on the leg extensors. A contact mat / computer system is used to record jump height and contact time.

The athlete is instructed to jump for maximum height and minimum contact time. Performance is measured as: height jumped [cm] / contact time [sec].

After each jump immediate feedback is given to the athlete regarding height, contact time and performance (height / time).

This test produces a relatively small range of motion at the knee and contact times, ranging from 125-200ms, are virtually identical to the take-off times for the jumping events (HAY and MILLER, 1985; NIXDORF and BRÜGGEMANN, 1990; CONRAD and RITZDORF, 1990). The need to decelerate the downward velocity of the body in a short time from a relatively high drop height causes high stretch loads to be placed on the leg extensors. A similar situation is encountered in the take-off phase of the long, triple and high jumps,

REACTIVE STRENGTH (DROP JUMP)

Drop height [cm]	Jump height [cm]	Contact time [sec]	Reactive strength performance [Jump height/time]
30	38.9	0.155	251
45	40.8	0.153	267
60	40.1	0.141	284
75	37.1	0.142	261

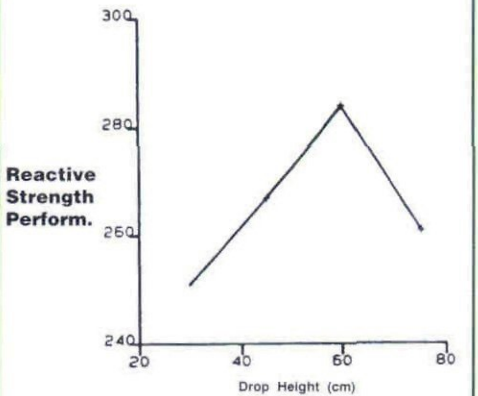

Figure 2: Example of drop jump results for a female triple jumper

as indicated by the large peak ground reaction forces, e.g. 12.6-22.3 times body weight for the step phase of the triple jump (RAMEY and WILLIAMS, 1985; AMADIO, 1985). Therefore the tolerance to high stretch loads is considered important for successful performance in jumping (BOSCO et al, 1976; YOUNG, 1987). The DJ test is considered to be a measure of reactive strength under fast SSC and high stretch loads.

This method of testing the DJ is preferred to the traditional DJ test of jumping only for maximum height, with no instruction relating to the contact time. A recent study conducted by the author (unpublished) demonstrated that the DJ (60cm drop height) for height only, produced a mean contact time of 421ms, which was 2.3 times longer than when maximum height and minimum contact time was the objective. In addition, the correlations between the DJ (for height only) and the DJ (height/contact time) was low (r+=0.37), non-significant, indicating that the two methods were measuring different qualities. The correlation between a CMJ (unloaded) and the DJ (height/contact time) was also low and statistically non-significant. These results support the suggestion that slow SSC/low stretch load (i.e. CMJ and DJ for height) and fast SSC/high stretch load tests (DJ height/time) measure independent qualities. This also explains why it is possible for a top high jumper to exhibit average results in a test such as the CMJ or vertical jump.

The DJ test results can be used to compare the reactive strength performance to norms and to other individual athletes. Also the drop height that corresponds to the best performance provides information about the athlete's ability to tolerate stretch loads. The higher the drop height, the better this ability. This 'optimum' drop height can be over 100cm for elite jumpers and can be used to prescribe DJ training (SCHMIDTBLEICHER, 1993). Intuitively it seems reasonable that a drop height (stretch load) below 'optimum' provides an insufficient overload and training stimulus, whereas a stretch load above the 'optimum' may cause a neuromuscular inhibition, resulting in a weakened contraction and training effect. The ability to make a training prescription immediately following the test has obvious appeal but the effectiveness of this practice has yet to be demonstrated.

Appropriate plyometric training (eg. DJ) should produce two effects:

1) Increase the reactive strength performance, due to an increased ability to apply more impulse in a shorter time, which is vital for sprinters and jumpers.
2) Increase the drop height resulting in the best performance. This should allow a high jumper, for example, to produce a more effective take-off from a faster run-up (stretch-load).

3.1.2 Force-time measures

- Maximum dynamic strength (MDS)

  This is the peak force developed during the jump movement and is immediately displayed in kg after each trial (*Figure 3*).

- Explosive strength

  This term has been used to describe the maximum rate of force development (RFD) in a maximum isometric contraction and is believed to be a measure of the number, force and speed of motor units involved in a contraction (SCHMIDTBLEICHER, 1986). This indicator of speed-strength has been shown to be sensitive to fluctuations in high jump performance (VIITASALO and AURA, 1984) but has been modified in SQAT to be measured under dynamic rather than static conditions.

- Starting strength (F 30)

  This quality has been described as the force produced at the start of contraction and is believed to be important for accelerating light loads (SCHMIDTBLEICHER 1992; TIDOW

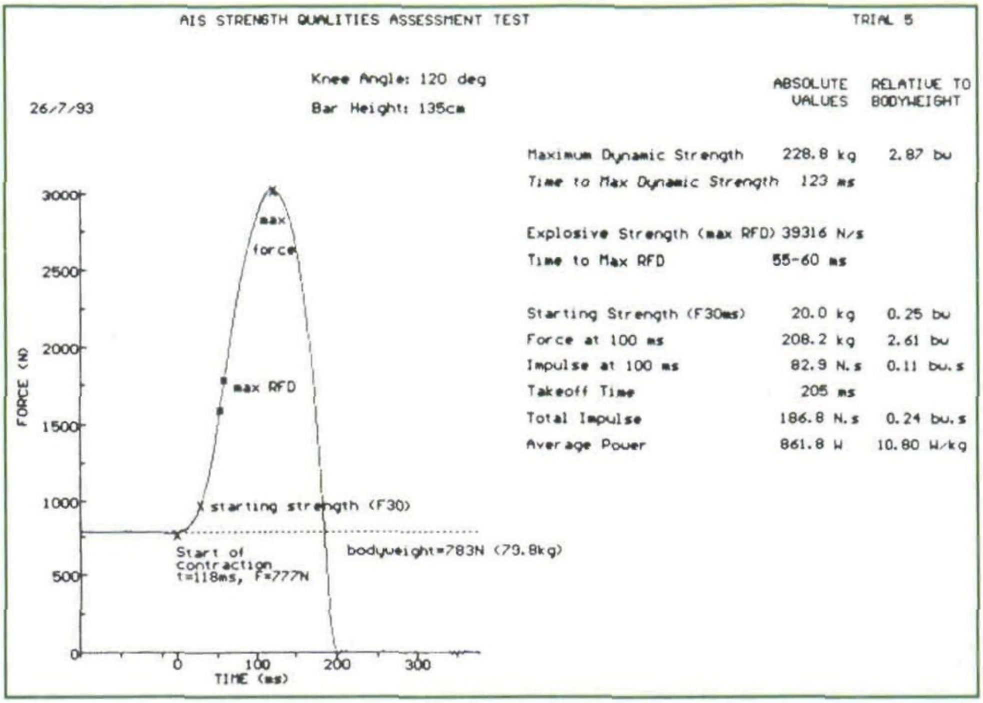

Figure 3: Computer display of results from one trial indicating the force-time curve

1990). SQAT measures starting strength as the force developed in 30ms from the start of a concentric contraction. Since starting strength represents, on average, 8% of maximum strength and has a very low correlation with maximum strength (r=.16, non-sig.), it is considered to be a measure of very fast force production capabilities.

- Force/Impulse in a specified time

  This is the force and impulse developed in a specified time from the start of concentration. The time is a variable that can be selected by the tester prior to the testing session. Since the duration of the sprinting and horizontal jumping support phase is close to 100ms, the force and impulse developed in this time has been used for the assessment of track and field athletes.

- Average power

  This is the average mechanical power developed throughout the concentric jumping action.

Other force-time measures include total impulse, take-off time, as well as the time taken to reach MDS and the maximum RFD. Force and power results are expressed in relation to body weight as well as in absolute terms.

3.2 Maximum strength

The maximum force generation capacity of the muscles (maximum strength) is considered to be a basic quality that influences speed-strength performance (SCHMIDT-BLEICHER, 1992). This is determined by an isometric squat from a 120° knee angle, which is within the range reported to produce maximum force for the knee extensors (KULIG et al, 1984). The athlete is instructed to develop the force slowly and progressively until no force increase can be detected by computer. Due to the large forces that can be generated in this test, various safety precautions are always taken.

- Maximum dynamic strength index (MDSI)

  This is the MDS expressed as a percentage of the maximum strength value and is used as an indicator of the proportion of maximum strength that can be developed dynamically. This measure can be used to determine when an athlete should switch the emphasis from maximum strength training methods to speed-strength methods, or vice-versa. For example, if heavy strength training reduced the MDSI to below 50%, the training emphasis should be changed to the development of explosiveness (speed-strength).

SQAT V2.2 **AIS STRENGTH QUALITIES ASSESSMENT TEST** 18/11/93

BEST RESULTS OF TRIALS 2 3 4 5 7 8 9 10 11

File:

Date: 17/11/93

Name:

Sport: Triple jump

Weight: 57.0

---------SPEED STRENGTH QUALITIES------------

....*JUMP TEST (90 deg Knee Angle)*.....Bar Height: 115 cm

Squat Jump (SJ)	37.7 cm
Counter Movement Jump (CMJ)	41.1 cm
Reactive Strength (CMJ-SJ)	3.4 cm

....*JUMP TEST (120 deg Knee Angle)*....Bar Height: 132 cm

		RELATIVE TO BODYWEIGHT
Maximum Dynamic Strength (MDS)	174.7 kg	3.07 bw
Time to MDS	90 ms	
MDS Index	65 %	
Explosive Strength (max RFD)	39316 N/s	
Time to Max RFD	36- 41 ms	
Starting Strength (F30ms)	39.6 kg	0.69 bw
Force at 100 ms	172.0 kg	3.02 bw
Impulse at 100 ms	91.1 N.s	0.16 bw.s
Takeoff Time	190 ms	
Total Impulse	126.7 N.s	0.23 bw.s
Average Power	553.3 W	9.71 W/kg

....*REACTIVE STRENGTH (DROP JUMP)*.....

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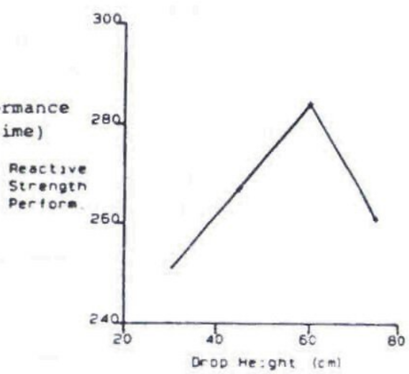

MAXIMUM STRENGTH (120 deg knee angle) 270.3 kg 4.74 bw
2652 N

COMMENTS:

Figure 4: Example of results print-out for a female triple jumper

An unlimited number of trials are allowed and the best score is used as the final result. An example of a results report for a female triple jumper is shown in *Figure 4*. This was available to the coach and athlete immediately after the testing session.

4 Interpretation of results

If any test battery is to provide good diagnostic potential, norms for test measures must be available. Since SQAT is a unique system, efforts are presently being made to collect results for normative data and to determine the relationship between the strength qualities measures and performance. Biomechanical and strength tests were recently conducted on elite junior athletes at the IAS, to observe the relationship between the strength qualities measured by SQAT and sprinting performance. Of the SQAT measures, the force and impulse generated in 100ms were significantly related to maximum sprinting speed ($r=0.74-0.80$; $p=0.0004-0.0001$). It was also found that the best predictors of starting ability (time to 2.5m from a block start) were all concentric contraction qualities and were more related to maximum strength than very fast force abilities. This was not surprising, since the block start and first foot contact are predominantly concentric actions and the movement times are relatively slow (approx. 350-200ms) (MERO, 1988). These results provide support for the value of SQAT measures for diagnostic purposes.

Based on statistical analysis, starting and explosive strength can be shown to represent fast force production abilities, whereas the CMJ is fairly equally influenced by maximum strength and fast force ability.

Table 1: Some SQAT results from two female sprinter/jumper athletes

Strength measure	Athlete A	Athlete B
CMJ [cm]	41.4	42.6
Starting strength [kg]	36.8	16.3
Explosive strength [N/s]	54.457	24,908
Maximum strength [Bodyweight]	4.05	5.01

The profiles shown in *Table 1* indicate that the CMJ was unable to distinguish clearly between two female athletes. However, athlete A has clearly better fast force abilities and athlete B has the better maximum strength. Both athletes achieve a similar CMJ through different means. It was only the ability to isolate maximum strength and fast force capabilities that allowed the athletes to be clearly separated.

5 Conclusion

In conclusion, some proposed advantages of the SQAT battery for assessment of track and field athletes include:

- It assesses a broad spectrum of strength qualities from maximum strength to fast force production.
- It assesses speed-strength qualities in a dynamic accelerated movement.
- It includes measures of speed-strength in SSC conditions.
- It involves multi-joint movements similar to those used in running and jumping.
- Immediate feedback is provided after every trial and a printed report of results is available to the coach and athlete immediately after testing.
- It can be modified to include upper body tests e.g. specific shot put movements.

Laboratory assessment of strength qualities can be designed to be sport-specific and should be used in conjunction with traditional field tests, to provide detailed information about an athlete's profile and progress.

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